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Effects of Atrazine on Community Level Responses in Taub Microcosms

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Effects of Atrazine on Community Level Responses in Taub Microcosms

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ABSTRACT: As part of a study to evaluate laboratory toxicity screening tests that include single species bioassays and microcosms, we examined community level responses in Taub microcosms exposed to atrazine (60, 100, 200, 500, 1000, and 5000 μg/L), a commonly used herbicide. Measurements of community metabolism included primary productivity, community respiration, primary production efficiency, and productivity/respiration (P_n/R_n) ratios. These community measurements varied in their sensitivity to atrazine. Primary production efficiency (primary productivity per unit chlorophyll) appeared to be the most sensitive measurement with greatly reduced efficiencies occurring throughout the experiment at atrazine exposures of 60 μg/L. The other community measures appeared to be more sensitive to atrazine during the interval when *Daphnia magna* populations were highest, suggesting increased pressure by *D. magna* on primary producers increased the sensitivity of this test system to atrazine. All community metabolism measurements of the microcosms exposed to higher atrazine concentrations of 500, 1000, and 5000 μg/L differed from controls throughout the experiment.

KEY WORDS: aquatic ecosystems, microcosm, atrazine, community metabolism, productivity/respiration ratios, primary productivity, respiration

Considerable information is available on the response of single species bioassays and model ecosystems to a variety of toxicants. Since the goal of most of these tests was not for inter-test comparisons, much of this information cannot be used for this purpose. Also, because comparable information for responses of natural ecosystems to toxicants is scarce, the accuracy and predictive capabilities

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of most of these tests have not been evaluated [*1*]. As part of our work to evaluate laboratory screening tests, we are comparing the sensitivity and accuracy of several different freshwater assay systems. The general objectives of the experiments reported here are to describe the impact of a toxicant on a gnotobiotic multispecies microcosm of a pond or lake ecosystem and to compare these effects to those that are noted in the literature for outdoor semi-natural or natural systems; only qualitative comparisons of microcosm results will be made at this time. The accuracy of the quantitative predictions made from these experiments and others will be evaluated when the field phase is completed.

The Taub microcosm was selected for these experiments because it has a well developed protocol and is a generic, rather than site-specific, system that contains multispecies-representatives of primary producers, decomposers, and primary consumers. Also, many of the interactions between these trophic levels have been described for several types of toxicants [*2–4*]. These features make this microcosm system a likely candidate for use in screening toxic chemicals.

Atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) was selected as the toxicant for these experiments because of its widespread use as an herbicide in the United States [*5*] and the wealth of information relating to its impact on aquatic organisms [*6–9*]. Atrazine inhibits photosynthesis through blockage of electron transport in the Hill reaction [*10*]. Because of its direct effect on primary production, the variables primary productivity (^{14}C-uptake), net primary productivity (O_2 method), community respiration, net productivity/respiration (P_n/R_n) ratios, and productivity per unit chlorophyll *a* (^{14}C-uptake/chl *a*) were used to describe the effect of atrazine on the microcosm community. Other structural and process measurements that were made during this study (according to the Taub protocol) will be presented elsewhere.

Materials and Methods

Microcosms were constructed and operated according to a protocol developed by Taub [*11,12*]. This microcosm consists of a 3.7-L widemouth pickle jar that contains 3 L of Taub and Dollar media [*13*] and 200-g white silica sand enriched with 0.5-g ground chitin and 0.5-g ground cellulose. The microcosms were autoclaved, cooled to incubation temperature, and ten species of algae (Table 1) were added to create an initial microcosm concentration of 1000 cells/mL for each species (Day 0). *Daphnia magna* and the other animals were added on Day 4 (Table 1). A stock of 23-mg/L atrazine was prepared using reagent grade atrazine and Taub and Dollar media. On Day 7, appropriate amounts of this solution were added to the 27 of 30 microcosms with the most similar dissolved oxygen (DO), algal counts, *D. magna* counts, and primary productivity; no additional atrazine was added for the remainder of the experiment.

These microcosms were incubated at 20 ± 1°C under 900 ± 100 foot-candle cool-white fluorescent bulbs (GE F96PG17.CW) with a light cycle of 12 h on and 12 h off. On Tuesday and Friday of each week from Day 7 to Day 60, measurements of DO, ^{14}C-uptake, chlorophyll *a*, and *D. magna* were made. Before

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TABLE 1—*Concentration of biota added to each microcosm.*

Algae[a] (Added to Day 0)	Animals (Added on Day 4)	
	Organism	Initial Number/ Microcosm
Anabaena cylindrica	*Daphnia magna* (Cladoceran)	6 large (3 gravid), 10 small
Chlamydomonas reinhardi	*Hyalella azteca* (Amphipod)	3 mating pairs, 6 small
Chlorella vulgaris	*Cypridopsis* sp. (Ostracod)	6
Nitzschia kutzigiana	*Philodina* sp. (Rotifer)	90
Scenedesmus obliquus	*Hypotricha* (Protozoan)	330
Selenastrum capricornutum		
Ankistrodesmus sp.		
Lyngbya sp.		
Stigeoclonium tenue[b]		
Ulothrix subconstricta[b]		

[a]Each algal species was added to achieve an initial microcosm concentration of 10^3 cells/mL.
[b]Tentative species identification.

measurements were taken or samples removed, periphyton was scraped from the walls and microcosms were well mixed. All measurements were made from 5 cm below the surface. No additional solute was added to replace microcosm volume lost to evaporation and sample collection.

The number of replicates used for the control and each treatment concentration was five controls, five at 60 μg/L, three at 100 μg/L; five at 200 μg/L, five at 500 μg/L, three at 1000 μg/L, and one at 5000 μg/L. These concentrations were selected to describe the effect of atrazine through time as presented here and to develop dose-response curves that will be used for comparisons with other studies. The latter will not be presented in this report.

Whenever possible, all analyses were conducted according to U.S. Environmental Protection Agency methodology [*14,15*]. Atrazine was extracted from a 100-mL water sample with 20 mL of pesticide-quality ethyl acetate followed by concentration of extract and analysis by gas liquid chromatography with a nitrogen-phosphorus flame ionization detector [*16,17*]. Atrazine concentration in the microcosms was measured on Days 7, 28, 53, and 60.

Algae were filtered from 20-mL samples of microcosm media with glass fiber filters (Millipore AP 40 024 05) and analyzed for chlorophyll *a* according to Lorenzen [*18*]. Acid concentration used for phaeophytin correction was reduced to 8×10^{-3} *M* HCl [*19*] in order to avoid interferences resulting from shifts in absorption spectra of non-chlorophyll pigments that result in negative chlorophyll *a* values.

Primary productivity (^{14}C-uptake) was measured by the standard ^{14}C-HCO_3 method using 15-mL samples collected from each microcosm and incubated for 1 h at microcosm light intensities. A YSI Model 54 dissolved oxygen meter was used to measure DO. Net primary productivity and respiration were estimated by the amount of DO change in the microcosms during the 12-h light/12-h dark periods, and corrected for the amount of oxygen exchanged with the atmosphere.

The exchange rate with the atmosphere was estimated using Eq 1 [*15*]. The mass transfer coefficient (K_{LA}) was determined specifically for physical conditions used in these experiments (Eq 2) and then adjusted for the microcosm volume (Eq 3). The mass transfer coefficient (K_{LA}) used for these experiments was 0.026 h^{-1} at a microcosm volume of 2 L.

$$dc/dt = K_{LA}(C_s - C) \tag{1}$$

$$K_{LA} = \frac{\ln \dfrac{C_s - C_1}{C_s - C_2}}{t_2 - t_1} \tag{2}$$

$$K_v = \frac{V_s}{V_t} K_{LA} \tag{3}$$

where

dc/dt = oxygen transfer rate (mg/L/h),
K_{LA} = mass transfer coefficient (h^{-1}),
C_s = DO saturation at experimental conditions (mg/L),
C = DO at time (t) (mg/L),
C_1 = DO at t_1 (mg/L),
C_2 = DO at t_2 (mg/L),
t = time (h),
K_v = mass transfer coefficient corrected for microcosm volume at time (t),
V_s = volume used in developing K_{LA}, and
V_t = microcosm volume at time (t).

During the dark cycle, DO change was estimated by

$$dc/dt = K_{LA}(C_s - C) - R_{ni} \tag{4}$$

where R_{ni} = respiration rate (mg/L/h).

We assumed respiration occurred at a constant rate for 12 h.

Integrating Eq 4 and solving for respiration results in

$$R_{ni} = K_v \left[\frac{(C_s - C_t) - (C_s - C_0)e^{-K_v t}}{1 - e^{-K_v t}} \right] \tag{5}$$

where

C_0 = DO at the start of the dark cycle,
C_t = DO at the end of the dark cycle, and
t = 12 h.

During the light cycle, DO change was

$$dc/dt = (P_g - R) + K_v(C_s - C) \tag{6}$$

where P_g = gross primary productivity.

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Integrating Eq 6 and solving for net productivity (P_n)

$$P_n = K_v\left[\frac{C_t - C_s - (C_0 - C_s)e^{-K_v t}}{1 - e^{-K_v t}}\right] \tag{7}$$

where $P_n = (P_g - R)$ = net productivity (mg/L/h).

The production/respiration ratio (P_n/R_m) was calculated using net primary production and 12-h dark community respiration [*11,20*] in Eqs 5 and 7, respectively. Primary productivity per unit chlorophyll (^{14}C-uptake/chl *a*) is defined in these experiments as the ratio of ^{14}C-uptake to chlorophyll *a* concentration.

Daphnia magna counts were made on 100 mL of water collected from each microcosm after it had been gently mixed using a glass rod to uniformly distribute the *D. magna*. Mixing did not appear to injure the organisms and the microcosm contents settled in 2 to 4 h. *Daphnia magna* were counted immediately after collection, and then *D. magna* and media were returned to the microcosm.

Data for each of the measures of community metabolism were analyzed to determine concentrations and times where treatments differed from controls. Statistical analyses included the use of the Cochcran C [*21*] and the folded F Test [*22*] to determine homogeneity of replicate variances. When replicate variances of a particular variable were not significantly ($P < 0.05$) different, a linear contrast (*t*-test) with pooled variance was used to determine probability of difference between control and treatment groups. When the replicate variances were significantly ($P < 0.05$) different, linear contrasts and degrees of freedom were calculated with a nonpooled variance [*23*].

Results

^{14}C-Uptake

Primary productivity (^{14}C-uptake) was almost completely inhibited for the entire experimental period by treatments of 500, 1000, and 5000 μg/L atrazine (Fig. 1). To enhance visual clarity, only the 500 μg/L treatment is illustrated and represents the characteristic trend of these three highest treatment levels. The ^{14}C-uptake in microcosms treated with 60, 100, and 200 μg/L atrazine remained significantly ($P < 0.05$) different from the controls through Day 20. Following Day 14, productivity in the controls decreased sharply to a level similar to the 100 μg/L treatment. This decrease occurred during the onset of a *D. magna* bloom and when nutrients (nitrogen and phosphorus) generally reach minimal concentrations.

During the time when *D. magna* densities were highest (Days 18 to 35) the differences between the ^{14}C-uptake rates were greatest for the 60, 100, and 200 μg/L treatments. Following the *D. magna* bloom, the difference between the productivity rates of these three treatments was reduced and they remained similar to that of the control for the remainder of the experiment.

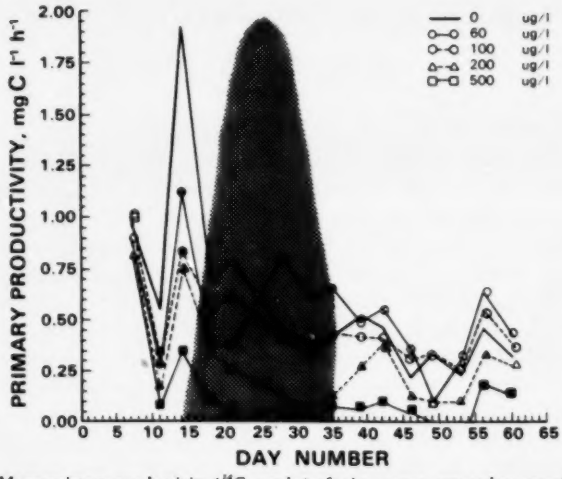

FIG. 1—*Mean primary productivity (^{14}C-uptake) of microcosms exposed to atrazine. Points of significant ($P < 0.05$) linear contrast from control are presented with darkened symbols. The shaded region represents the* D. magna *bloom.*

Dissolved Oxygen

Following atrazine addition, DO concentration at the end of both the dark (Fig. 2) and light (Fig. 3) periods decreased sharply in microcosms treated with 500, 1000, and 5000 μg/L atrazine (represented by the 500 μg/L line) and generally remained below 3.0 mg/L until after the *D. magna* bloom had passed. After the *D. magna* bloom, DO at the end of the dark period gradually approached that of the controls and DO at the end of the light period in the 500, 1000, and 5000 μg/L treatment microcosms gradually approached DO saturation (9.07 mg/L) but did not reach control levels. Dissolved oxygen at the end of the light period at these three high treatment levels remained significantly ($P < 0.01$) less than that of the controls for the complete experimental period.

Dissolved oxygen in microcosms treated with 60, 100, and 200 μg/L was between that at higher treatment levels and that in the controls. On the sampling day following atrazine addition (Day 11), the reduction of DO at the end of both photoperiods appeared somewhat proportional to the treatment level and concentrations were significantly ($P < 0.01$) less than in the controls. On Day 14, the day of maximum primary productivity, DO at the end of the light period in the 60 and 100 μg/L treatments increased to values similar to those in the controls and only DO in the 200 μg/L treatment microcosm remained significantly ($P < 0.01$) less than that in the controls. During the *D. magna* bloom, the DO in the 100 and 200 μg/L treatments generally remained significantly ($P < 0.05$) less than in the controls. The 60 μg/L treatment was significantly ($P < 0.01$)

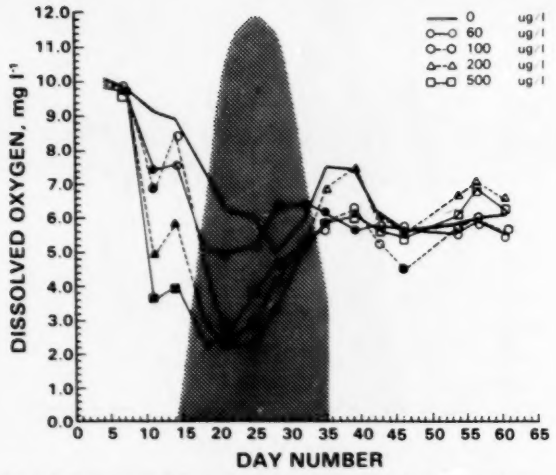

FIG. 2—*Mean DO concentration at the end of the 12-h dark cycle in microcosms exposed to atrazine. Symbols as in Fig. 1.*

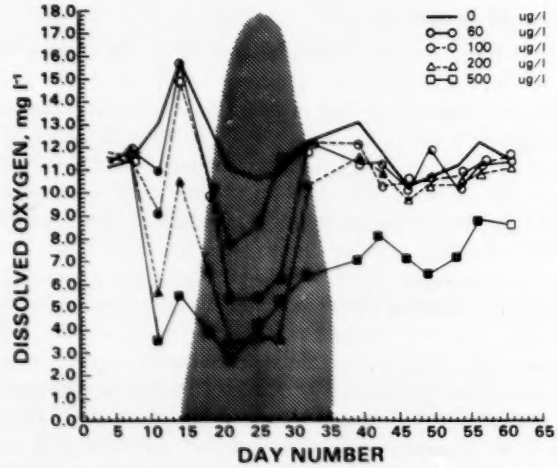

FIG. 3—*Mean DO concentration at the end of the 12-h light cycle in microcosms exposed to atrazine. Symbols as in Fig. 1.*

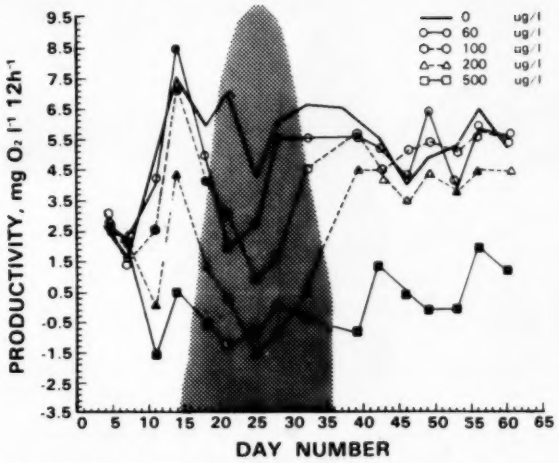

FIG. 4—*Mean net primary productivity* (P_n) *in microcosms exposed to atrazine. Symbols as in Fig. 1.*

less only on Day 21. Following the *D. magna* bloom, DO at the end of both photoperiods in the 60, 100, and 200 μg/L treatments approached that of the control and differences were no longer significant ($P < 0.05$).

Net Productivity and Respiration

Because DO deviated greatly from saturation during the experiment, it was necessary to estimate the contribution of reaeration to the oxygen regime in order to estimate both net productivity and respiration. This correction resulted in a maximum change of 1.8 and 1.5 mg O_2/L/12 h between corrected and uncorrected net productivity and respiration, respectively. Net productivity (Fig. 4) in microcosms treated with 500, 1000, and 5000 μg/L was significantly ($P < 0.01$) less than that of the controls and generally remained less than 1 mg O_2/L/12 h with very little recovery during the entire experiment. Because net productivity is the difference between gross productivity and respiration, negative values frequently occurred when production was less than respiration at these higher treatment levels. Net productivity in microcosms treated with 60 and 100 μg/L was similar to that of the controls until the *D. magna* bloom. During the *D. magna* bloom, net productivity in these microcosms deviated greatly from that of the controls and differences were significant ($P < 0.01$) during the growth phase of the *D. magna* bloom but not after. Although differences were large during the later part of the bloom period, variances among replicates also increased and differences were not significant ($P < 0.05$). Following the bloom, net productivity in the 60 and 100 μg/L treatments recovered to near control levels. Net productivity in the 200 μg/L treatment remained significantly

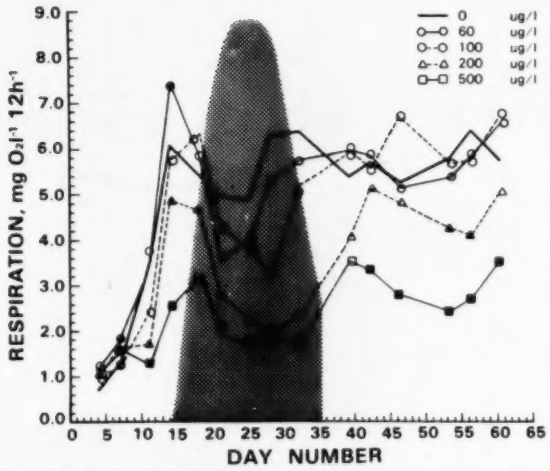

FIG. 5—*Mean 12-h dark respiration* (R_n) *in microcosms exposed to atrazine. Symbols as in Fig. 1.*

($P < 0.01$) below that of the control until the end of the *D. magna* bloom and then recovered to near control levels.

Respiration in microcosms treated with 500, 1000, and 5000 μg/L remained at pretreatment levels immediately following atrazine addition and then gradually increased during the remainder of the experiment (Fig. 5). Respiration in the 60 and 100 μg/L treatments was the same or greater than that of the controls both before and after the *D. magna* bloom. During the *D. magna* bloom, respiration in these two treatments was consistently less than that of the control. Differences, however, were not generally significant ($P < 0.05$) because of the concomitant increased variation among replicates. Respiration in the 200 μg/L treatment generally remained significantly ($P < 0.01$) less than that of the control until the end of the *D. magna* bloom. After the *D. magna* bloom, respiration in the 200 μg/L treatments recovered to near control levels.

P_n/R_{ni} *Ratio*

Although atrazine affected both the primary productivity and respiration of these microcosm communities, the impact on the balance and stability of these two community processes can best be seen with a productivity/respiration (P_n/R_{ni}) ratio (Fig. 6). During the first 20 days of the experiment, the P_n/R_{ni} ratio in the control remained above one, which is what might be expected for the nutrient-rich Taub and Dollar medium. During the remainder of the experiment, the P_n/R_{ni} ratio in the controls generally remained near one.

In microcosms treated with 500, 1000, and 5000 μg/L, the P_n/R_{ni} ratio decreased sharply to less than 0.4 and generally remained significantly ($P < 0.01$) lower than in the controls throughout the experiment. The P_n/R_{ni} ratio in the

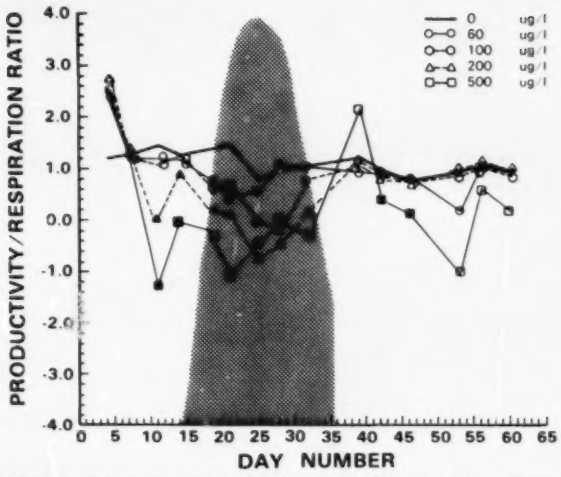

FIG. 6—*Mean net primary productivity/respiration* (P_n/R_m) *ratios in microcosms exposed to atrazine. Symbols as in Fig. 1.*

200 μg/L treatment also remained significantly ($P < 0.01$) less than in the controls. However, after the *D. magna* bloom, the ratio in the 200 μg/L treatments returned to near one and remained stable for the remainder of the experiment. The P_n/R_m ratio in the 60 and 100 μg/L treatments remained consistently less than that of the controls during the first half of the experiment, however, the difference was not generally significant ($P < 0.05$). During the second half of the experiment, the P_n/R_m ratio in both the 60 and 100 μg/L treatments remained near control values.

^{14}C-Uptake/Chl a Ratio

The ^{14}C-uptake/chl *a* ratio (Fig. 7) was the most sensitive measure of the effects of atrazine. Throughout the experiment, this ratio was significantly ($P < 0.01$) greater in the controls than in the treatment microcosms. The differences among all treatments was small relative to that between treatments and controls and the ratios in the 500, 1000, and 5000 μg/L treatments generally were less than those in the 60, 100, and 200 μg/L treatments. Unlike the other measurements, the ^{14}C-uptake/chl *a* ratio of the treatments did not appear to be affected by the *D. magna* bloom.

Discussion

It appears that the responses of the Taub microcosms to the atrazine treatment levels used in these experiments fell into two general categories: one associated with the high treatment levels (500, 1000, and 5000 μg/L), and the other asso-

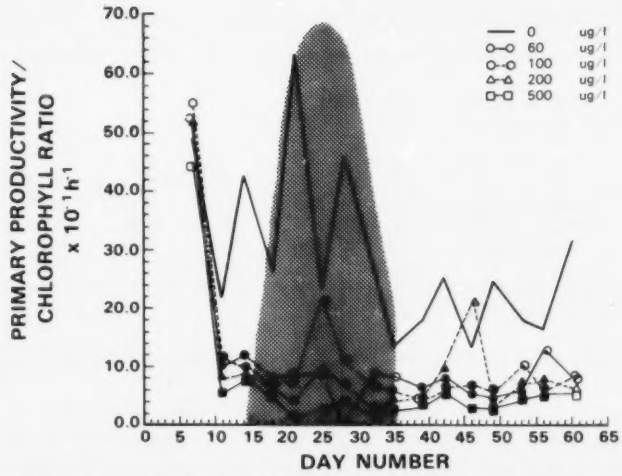

FIG. 7—*Mean primary productivity/chlorophyll a (^{14}C-uptake/chl a) ratios in microcosms exposed to atrazine. Symbols as in Fig. 1.*

ciated with low treatment levels (60, 100, and 200 μg/L). In the high treatment microcosms, all variables measured in this study declined immediately in response to added atrazine and remained suppressed throughout the experiment with little or no recovery. The only exception to this was DO at the end of the light and dark periods. The recovery that did occur in DO appeared to be the combined result of reduced respiration and reaeration, and not a recovery in primary production.

In the lower treatment microcosms (60, 100, and 200 μg/L), the effects of atrazine were apparent but not consistent throughout the 60-day experiment. Responses through time for these lower treatment levels could be divided into three main phases. The first, from Days 0 to 18, was dominated by high autotrophic growth, low *D. magna* grazing, and high, then declining nutrient concentrations. The second phase included the *D. magna* bloom that occurred between Days 18 and 35. During this phase, nutrients (nitrates and phosphates) probably reached minimal concentrations and the response of measured variables to atrazine increased. Unfortunately, nutrient samples collected for this period were contaminated and could not be used to describe the nutrient status before Day 30. Other experiments conducted by us and others [*24*] have shown that nutrients reach minimal concentrations during the first half of this phase and that control microcosms reach minimal concentrations before treatment microcosms.

The third phase, Days 35 to 60, followed the *D. magna* bloom and appeared to be a period of equilibrium, when factors limiting autotrophic processes, possibly nutrient recycling rates, exerted more control than did exposure to these lower atrazine treatments. This reduced response to atrazine was also due, at least in

TABLE 2—*Mean atrazine concentration (± standard deviation) for microcosms treated with nominal concentrations of 0, 60, 100, 200, 500, 1000, and 5000 μg/L atrazine.*

Nominal, μg/L	Day 7,[a] μg/L	Day 28, μg/L	Day 53, μg/L	Day 60, μg/L
0	<2.0	<2.0	<2.0	<2.0
60	52.4 (± 2.1)	48.4 (± 4.8)	40.8 (± 6.4)	33.7 (± 8.0)
100	84.1 (± 4.0)	62.8 (± 7.5)	59.8 (± 6.0)	51.1 (± 12.1)
200	169.3 (± 9.5)	114.3 (± 17.2)	94.6 (± 9.3)	98.3 (± 21.8)
500	430.2 (±16.9)	263.6 (± 38.7)	222.8 (±71.9)	197.9 (± 90.5)
1000	820.3 (±34.5)	504.7 (±127.0)	443.3 (±86.6)	416.7 (±105.0)
5000	3980.0	1890.0	1390.0	1540.0

[a]Atrazine was added to the microcosms on Day 7.

part, to the loss of atrazine that occurred during the experiment (Table 2), and to some recovery of the microcosm community.

During the first phase of the experiment when nutrients were not at minimal concentrations and *D. magna* densities were low, differences in ^{14}C-uptake between the control and these lower treatments were greatest. Differences among the treatments, however, were small. Net productivity was somewhat different in that the 60 and 100 μg/L treatments did not deviate greatly from the controls as did ^{14}C-uptake during maximum production (Day 14). Dissolved oxygen at the end of both photoperiods appeared to reflect these effects of atrazine on primary production. After Day 11, only DO in the 200 μg/L treatment microcosm remained significantly ($P < 0.05$) different during this first phase. Community respiration appeared to be the process least affected by atrazine. Respiration in these low treatment microcosms was generally not significantly ($P < 0.05$) different from the controls during the first phase, which suggests the effect of atrazine was not an increase in mortality but a reduction in autotrophic growth, as might be expected based on atrazine's mode of inhibition.

During the second interval, delineated by high *D. magna* densities, differences in ^{14}C-uptake, respiration, net productivity, and DO concentrations among the treatments were all greatest. This consistent increase in variation among the treatment means during this interval implies an increase in sensitivity to atrazine when the microcosm community is in a phase of rapid adjustment to nutrient depletion and changing *D. magna* populations. If this period of increased sensitivity is a general characteristic of microcosm systems subjected to a variety of stressors, it might be appropriate to use such intervals as the period of time for standardizing reports of microcosm tests.

During the third phase (equilibrium phase) ^{14}C-uptake, net productivity, DO, and respiration in the low treatment microcosms were similar to those in the control microcosms, indicating a period of recovery from atrazine stress. The only exception was respiration in the 200 μg/L treatments. Respiration at this treatment level remained less than that in the controls.

The two ratios, P_n/R_n and ^{14}C-uptake/chl *a*, used in this study as additional measures of atrazine-induced stress did not appear to conform to the three inter-

vals just described. The P_n/R_{ni} ratios have been used by others as an indicator of stability [*20,25*] and of stress-induced changes [*1,26*] in the overall metabolism of microcosms. In our experiments, control P_n/R_{ni} ratios initially exceeded one when primary production was high, then stabilized near one and did not deviate much throughout the experiment, in spite of large fluctuations in both net productivity and respiration. Control values presented here were similar to values summarized for other microcosms and natural systems [*1*].

Microcosms treated with 60 to 200 μg/L atrazine exhibited reduced P_n/R_{ni} ratios during the first half of the experiment and then their P_n/R_{ni} ratios recovered to control levels, indicating that the overall metabolism of the systems was temporarily affected at those low treatment concentrations. The P_n/R_{ni} ratios in microcosms treated with 500 to 5000 μg/L atrazine were reduced to very low values, less than zero on occasion, and also varied greatly with no apparent recovery.

The ^{14}C-uptake/chl *a* ratio is used as an index of the effectiveness of the algal photosynthetic systems. This ratio normalizes the rate of carbon fixed over the large range of chlorophyll *a* concentrations and ^{14}C-uptake rates found in these microcosms. In this study, it was the most sensitive measure of the effect of atrazine. In all treatment microcosms, it remained significantly ($P < 0.01$) less than in the control microcosms throughout the study, suggesting that the effectiveness of the photosynthetic system remained impaired at the lowest concentration (60 μg/L) tested and did not recover even though primary productivity rates recovered to control levels. The low values found here were due to increased chlorophyll *a* per unit biomass as well as a reduction in ^{14}C-uptake in the treatment microcosms.

In order to evaluate the accuracy or usefulness of these microcosm results for predicting responses in natural systems, we compared our findings to the interim results of studies being conducted by deNoyelles et al to determine the effects of atrazine on semi-natural pond communities [*27,28*]. Treatment concentrations used in their studies were 20, 100, 200, and 500 μg/L atrazine. deNoyelles et al found reduced ^{14}C-uptake at the lowest atrazine concentration tested (20 μg/L) and almost complete inhibition at 500 μg/L. The time required for ^{14}C-uptake to recover was shortest (four days) for the 20 μg/L treatment, and longest (24 days) for the 500 μg/L treatment. Recovery time for the ponds treated with 100 and 200 μg/L was similar to that of the 500 μg/L treatments. The response of ^{14}C-uptake in the microcosm was very similar to that of the ponds in that 500 μg/L and greater treatments almost completely inhibited ^{14}C-uptake and the 60 and 100 μg/L treatments resulted in significantly ($P < 0.01$) less ^{14}C-uptake with recovery to control levels occurring during the experimental period as it did in the ponds. Microcosms differed from the ponds, however, in that they appeared to lack the ability to recover at the 500 μg/L treatment level.

Reduced oxygen concentration in the ponds was apparent only at the 500 μg/L treatment level during the period of reduced primary productivity. The decrease ranged between 1.0 and 3.0 mg/L with minimum concentrations never de-

creasing below 4.0 mg/L. In the microcosms, the change was much more severe, with treatments of 200 μg/L and greater having DO concentrations frequently less than 4.0 mg/L. The 60 and 100 μg/L treatment microcosms also had reduced DO concentrations but not below 4.0 mg/L.

These differences are associated with two factors. First, the Taub microcosms are highly enriched, and might be typical of hypereutrophic conditions, thus they exhibit high oxygen demand; the ponds are much less productive, more nearly mesotrophic [*29*], thus they exhibit lower oxygen demand. Second, reaeration is likely to be significantly different between the two systems.

The measurement that appeared to be the least similar between the two systems was ^{14}C-uptake/chl *a* ratio. In the microcosms, this ratio remained significantly ($P < 0.01$) less in all treatments than in the controls, and did not recover during the experimental period. deNoyelles et al indicated they found no significant differences between controls and treatments and concluded that individuals or species with resistance had survived and become prominant in the resultant community. This capacity for the system to recover to control levels was not present in the microcosms to the extent it was in the ponds and is probably due to the limited number of different types of organisms present in the microcosm relative to that in the ponds.

Conclusions

Conclusions that can be made from this study are as follows.

1. The responses of the Taub microcosms to the atrazine treatment levels used in these experiments fell into two categories. In one category associated with high treatment levels (500, 1000, and 5000 μg/L), all process variables declined immediately in response to atrazine and did not recover during the experiment. In the other category, which was associated with the lower treatment levels (60, 100, and 200 μg/L), the magnitude of the responses to atrazine was not constant throughout the experiment and could be divided into three phases: an autotrophic phase, a *D. magna* bloom phase, and an equilibrium phase. The magnitude of microcosm response was generally greatest during the *D. magna* bloom phase and least during the equilibrium phase.

2. The major effect of atrazine on the microcosm was inhibition of primary production, and not acute mortality at treatments of 1000 μg/L and less. The ^{14}C-uptake/chl *a* ratio was the most sensitive measure of the effect of atrazine and data developed with this ratio suggest that, although primary productivity rates in the 60 to 200 μg/L treatments recovered to control levels, the effectiveness of the photosynthetic system remained impaired. Community respiration was the least sensitive measure of the effects of atrazine and differences were not significant ($P < 0.05$) at treatment levels of less than 200 μg/L atrazine.

3. Qualitative comparisons of these microcosm results and those of ponds treated with atrazine suggest both systems responded in a similar manner. The microcosm, however, lacked the capacity of the ponds to recover from 500 μg/L atrazine.

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